Exchanging data between Digital Human Modeling systems - A review of data formats

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Abstract

Digital human modeling (DHM) systems underwent significant development within the last years. They achieved constantly growing importance in the field of ergonomic workplace design, product development, product usability, ergonomic research, ergonomic education, audiovisual marketing and the entertainment industry. They help to design ergonomic products as well as healthy and safe socio-technical work systems. In the domain of scientific DHM systems, no industry specific standard interfaces are defined which could facilitate the exchange of 3D solid body data, anthropometric data or motion data. The focus of this article is to provide an overview of requirements for a reliable data exchange between different DHM systems in order to identify suitable file formats. Examples from the literature are discussed in detail. ***Methods:*** As a first step a literature review is conducted on existing studies and file formats for exchanging data between different DHM systems. The identified file formats can be structured into different categories: static 3D solid body data exchange, anthropometric data exchange, motion data exchange and comprehensive data exchange. Each file format is discussed and advantages as well as disadvantages for the DHM context are pointed out. Case studies are furthermore presented, which show first approaches to exchange data between DHM systems. Lessons learnt are summarized in short. ***Results:*** A selection of suitable file formats for data exchange between DHM systems is determined from the literature review.

Keywords: data exchange, data format, digital human modeling, DHM

1. Introduction

Digital human models have evolved as a helpful tool in research, product development and to design ergonomic products as well as healthy and safe socio-technical work systems. Various existing DHM systems manifest no default mutual compatibility (Paul and Wischniewski 2012). Several known issues restrict the claim for a completely standardized DHM-system (Keyvani 2013). Irrespective of this, the aim of this study was not to standardize algorithms or advance a standardized DHM morphology, since these relate to business models, and are therefore essential for developers. Notwithstanding the above, open standardized file formats for import- and export of DHM data would facilitate the exchange of information and thus foster further development of the DHM industry. Despite not solving the known issues regarding differences in underlying DHM conventions, as for example joint degrees of freedom (DoF), body, joint and force coordinate systems directly, a generally accepted data exchange file format (or set of file formats for specific use) will promote the design of standard plugins or interfaces to ensure a reliable data exchange by DHM and Motion Capture system developers. This would benefit researchers, software developers and end users who are currently limited and often confounded by a multitude of existing file formats and proprietary solutions.

2. Background

Several studies have been conducted over the last few years to enable data exchange between different DHM or motion capture systems. For industrial applications the use of digital human models saves resources, enables reproducibility, sensitivity analysis and investigations in early phases of the product (e. g. vehicle) or production

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design process. More than 150 DHM systems are globally available for workplace and product design, safety evaluation and documentation purposes (Bubb and Fritzsche 2009). They specialize on different aspects and their functionality can be categorized accordingly. Anthropometric human models for example represent the variability of human dimensions for posture prediction and workspace requirements, while biomechanical models support the simulation of physical behaviour.

Motion capture is used for motion analysis and to validate posture and motion predicted by DHM.

In fact, often different company departments use various, typically incompatible DHM and motion capture systems, depending on their needs, responsibilities and resources. The tools generate dedicated output parameters such as posture parameters (e. g. joint angles), biomechanical values (e. g. joint loads and muscle activation) or tissue reactions (e. g. deformation, pressure distribution, tissue strength). Those output parameters are used for specific ergonomic or comfort evaluations. For the holistic ergonomic assessment of a specific workload, the results of several specialized tools need to be considered and seen in combination. It should be possible to use outputs of one tool (e. g. posture) as input for other tools (e. g. biomechanical or material analysis) and vice versa to mutually increase the quality of results.

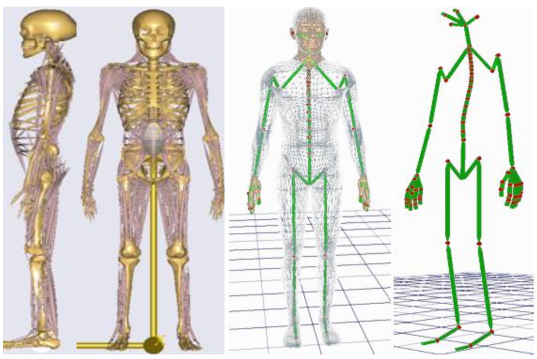
For industrial applications it is therefore necessary to simplify the data transfer between different departments and to enhance ergonomic evaluations by combining several different assessment criteria. This requires standardized data formats as a prerequisite for the development of a workflow which is user friendly, does not require programming skills, and only needs minimum input data to enable quick investigations in early stages of the design process, in a reusable format for several tools. If the workflow is too complicated or needs too many input parameters, acceptance in industrial usage will be low.

As a result of these industrial requirements several studies have been conducted over the last few years to enable data exchange between different DHM or motion capture systems (e.g. Rim et al. 2008, Paul and Lee 2011, Walther and Munoz 2012, Jung et al. 2013, Stephens et al. 2013). Common to all are the individual, customized solutions.

2.1. Case Study Jack-Anybody

Within this case study, two well-known DHM systems, namely JACK and Anybody Modeling System (AMS), were used. The Anybody Modeling System has been extensively reported in literature (e.g. Christensen et al. 2003, Damsgaard et al. 2006). The system is representative of a class of biomechanical, musculoskeletal multibody modeling systems, which are typically standalone; similar systems are OpenSimm (Delp et al. 2007), LifeModeler (McGuan 2001) or SIMM (Davoodi et al. 2001). An inherent issue with the AMS biomechanical modeling system is that in contrary to a high level of body part detail, as for example the mechanical properties of many hundreds of muscles and fasciae, the body in whole is not modeled, such that model anthropometry is not representative of a human. Opposed to these inside-out biomechanical models with lacking integral validity, traditional digital human models as used in product design reflect an outside-in approach, often with a realistic exterior appearance, but very limited internal model. Such models are typically based on representative anthropometric databases, as for example ANSUR, NHANES or CAESAR. Representatives for this class of digital human model are for example RAMSIS (Bubb et al. 2006), JACK (Badler et al. 1999) or DELMIA/Humanbuilder, previously SAFEWORK (Gilbert et al. 1989).

The industrial user generally needs a combination of both DHM worlds: accurate anthropometric proportions for valid man-machine interface modeling, and elaborate biomechanical properties for explicit human workload and musculoskeletal strain calculation. To model postural change under mechanical load, an interface program was developed to combine AMS and JACK functionality (Paul and Lee 2011). This software was facilitated by the PYTHON programming interface inherent in the JACK software. The interface program was therefore integrated and called from within JACK. A range of roadblocks complicate communication between the two models. The two human models use a different internal body model (biomechanical model), with inconsistent numbers of joints and segments. In addition, joint locations, range of motion (ROM) and joint coordinate systems vary (Fig. 1).



a) b)

Figure 1: AMS (a) vs. JACK (b) biomechanical model

To translate a posture from JACK to AMS, 26 mutual joints of significant importance for the skeletal structure were selected for a common biomechanical structure. Jack coordinate systems were reoriented to follow the orientation of joint coordinate systems in AMS in the Jack to AnyBody (J2A) translation, and JACK joint positions were used to scale the AMS skeleton. In the reverse translation after running an inverse kinematic analysis in AMS, the range of motion (ROM) of each joint was coordinated between AMS and JACK to account for JACK ROM limitations. AMS joint coordinate systems were then reoriented to follow the orientation of JACK joints in the AnyBody to Jack (A2J) phase.

Despite the scripting support through PYTHON, the case study shows significant issues when interfacing the two modeling systems, with the most significant being that the required rigid model of the interface contradicts flexible modeling assumptions, which are inherent in AMS. Given the JACK body model, anthropometric scaling is also not straight forward.

2.2. Case Study RAMSIS-Anybody-CASIMIR

The UDASim project represents ongoing industry efforts towards a comprehensive data exchange solution, designed as a 3-year funded research project which was started in 2013.

UDASim is a German national research project funded by the German Federal Ministry of Research and Technology. The German project acronym stands for "comprehensive discomfort simulation for car occupants" and the main objectives are (see figure 2):

- Development of a comprehensive discomfort assessment of a car driver via a neural network based on the following input:
    - Muscle & joint forces
    - Posture
    - Seat pressure distribution
    - Internal tissue stresses
- Development of an interfacing human model platform (CASIMIR, RAMSIS and AnyBody) for providing the input parameters

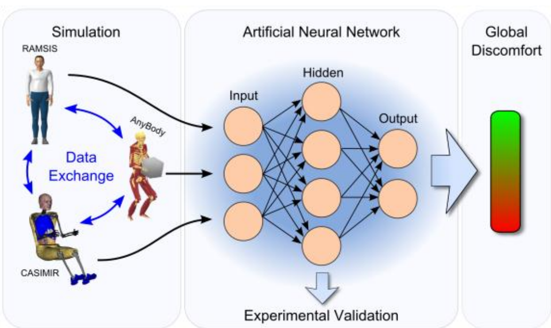


Figure 2: UDASim – Software architecture

The project consortium consists of the partners Wölfel (project leader, provider of CASIMIR), Human Solutions (provider of RAMSIS), Anybody Technologies (provider of Anybody, associative partner), Technische Universität München (science) as well as the automotive companies BMW, Daimler and Ford as associative (supporting) partners. An essential project task is to define and implement a human data exchange format for all involved human model tools.

The main components in exchanging data between different DHM systems are postural and anthropometrical information. Since DHM systems significantly vary in kinematical (e. g. joint rotation convention, spinal column resolution) and anthropometrical (e. g. body dimensions, skeleton and skin scaling) properties in general, a smallest possible exchange data level has to be found. In this context a common skeleton structure has been specified to transfer joint position information (see Table 1).

Table 1: Joint definitions for transfer

bvh joint	Anatomical definition	
Name	Joint between	End of site
LeftBall	mid-foot / toes (ossa metatarsi II / phalanges proximales II)	tip of phalanges distales II
LeftAnkle	lower leg / foot	-
LeftKnee	upper leg / lower leg	-
LeftHip	pelvis / upper leg	-
RightBall	mid-foot / toes (ossa metatarsi II / phalanges proximales II)	tip of phalanges distales II
RightAnkle	lower leg / foot	-
RightKnee	upper leg / lower leg	-
RightHip	pelvis / upper leg	-
PelvisCenter	global coordinate system / pelvis	-
LowerLumbarSpine	sacrum / ilium of pelvis (sacroiliac joint)	-
UpperLumbarSpine	L4 / L5 vertebra	-
LowerThoracicSpine	lumber / thoracic spine (T12 / L1 vertebra)	-
UpperThoracicSpine	T8 / T9 vertebra	-
LowerCervicalSpine	T4 / T5 vertebra	-
Chest	thoracic spine / thorax, chest, rib cage (upper rib 1 / T1)	
UpperCervicalSpine	C4 / C5 vertebra	-
Head	C1 vertebra / head	-
MidEye	head / line of mid eye vision	-
LeftClavicle	clavicle / thorax (clavicle / manubrium)	-
LeftShoulder	Shoulder / upper arm (scapula / humerus)	-
LeftElbow	upper arm / lower arm	-
LeftWrist	lower arm / hand	middle finger tip (tip of phalanges distales III)
RightClavicle	clavicle / thorax (clavicle / manubrium)	-
RightShoulder	Shoulder / upper arm (scapula / humerus)	-
RightElbow	upper arm / lower arm	-
RightWrist	lower arm / hand	middle finger tip

In order to exchange these data between human models the well-known animation format BVH (see section 4.2.) was selected. It has the additional advantage to transfer bone orientation information, when a common initial skeleton posture is specified (see figure 3).

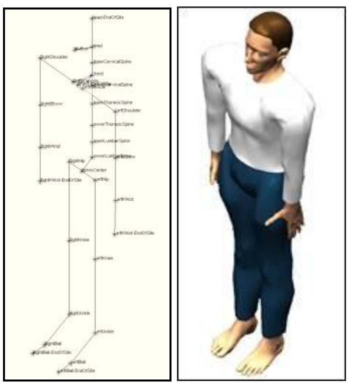


Figure 3: Common initial skeleton posture

Since exchanging just posture and anthropometric information is not sufficient in many applications, additional human model data has to be transferred, which is currently under development. This will include manikin parameters as body measures, weights, joint torques and forces as well as environmental parameters as seat parameters, seat pressure distribution and contact conditions between the human and its environment.
These parameters cannot be integrated in the BVH format, hence a XML format will be defined, which includes one node holding the BVH information as described above.

3. Methods

To identify related studies for the presented research context, a thorough literature review was conducted. Relevant studies were collected by appointing keywords in approved scientific electronic databases (EBSCO, PUBMED, SCIENCE DIRECT, WEB OF KNOWLEDGE): All variations of single keywords *Digital Human Model, Digital Human Manikin, DHM, Motion Capture, Ergonomic Simulation, Character Animation,* , combined with additional parameters *Data Exchange, Import, Export, File Format, Interface* and *Data Format* were included. For example: ("digital human model*" OR "digital human manikin*" OR "ergonomic simulation") AND ("data format" OR import OR export OR "file format" OR interface). In addition, a purposive review of the proceedings from the International Symposiums on Digital Human Modeling in Lyon (2011) and Ann Arbor (2013) was conducted. A following "citation snowballing" procedure completed the first comprehensive look. Appropriate studies were selected manually in terms of relevance and relation to DHM data exchange.
In a second search, common data exchange file formats were identified by examination of available file descriptions, user manuals, a broad internet search, analyzing developer- and vendor's webpages. Subsequently the identified file formats were allocated to the following categories: *3D solid body data exchange, motion data exchange, comprehensive data exchange and anthropometric data exchange.* Each file format was examined in detail and advantages as well as disadvantages for the DHM context were pointed out. The initial electronic database search identified 112 articles, 69 were excluded manually by reviewing title and abstracts only. Four Studies were selected from DHM proceedings. In total 47 studies with relevance to DHM systems remained, from which 23 studies or book sections were used in a data exchange context. The search for motion file formats returned nine useable official published works; furthermore seven sources were added from an internet search.

4. Results

Key-features of common file formats for exchanging DHM relevant data are presented as an overview of the most suitable formats, given that it is impossible to provide a complete overview of all available formats.

4.1. 3D solid body data exchange

IGES

IGES (Initial Graphics Exchange Specification) is a vendor neutral file format for exchanging data between CAD-systems, registered as a standard at American National Standards Institute (ANSI) ANS Y14.26M-1981. IGES is still a popular neutral format (Kamrani and Nasr 2006), but its most recent official version 5.3 was published in 1996. It seems like development stopped since the arising of the new ISO standard STEP (ISO 10303). IGES doesn't offer information for Product Lifecycle Management (Suziyanti et al. 2010), also the big file size and corresponding processing time might be inconvenient and restrictive for DHM use.

JT

The JT (Jupiter) file format is developed by Siemens PLM Software Inc. JT is a standardized file format for 3D data exchange (ISO IS 14306: 2012). The file format is well documented; for a detailed view see (SIEMENS 2010). JT is a convincing file format for DHM collaboration, because it is capable of a small file size (depending on the chosen geometry and detail level)while offering the possibility for expanding detail level up to exact boundary representation with surfaces (NURBS), product and manufacturing information (PMI) and metadata.

STEP

STEP (Standard for the Exchange of Product model data) is an International Standard (ISO 10303) for exchanging 3D data. STEP uses a special format data specification language, called EXPRESS. STEP offers comprehensive information to define the geometric shape of a product including topology, features, tolerance specifications, material properties. In summary STEP offers everything that is necessary to completely define a product and contains all necessary information for DHM needs. A review conducted in 2010 found that the STEP standard for product data exchange is more popular than the legacy format IGES (see: Suziyanti et al. 2010). The bigger file size and very complex file structure compared to other formats might be an inhibitor in the DHM context.

STL

STL (Stereo Litographie or Standard Tesselation Language) is a file format for rapid prototyping and computer-aided manufacturing. STL files describe the surface geometry of a three dimensional object without any representation of color, texture or other common CAD model attributes (Ciabota 2012). STL might be suitable for a first rapid look and, because of its small file size, for internet collaboration. If the developer needs more detailed information, other formats offer a more precise and scalable structure.

4.2. Motion File Formats

ASF / AMC

ASF and AMC file formats were developed by Acclaim Entertainment Inc. The ASF (Acclaim Skeleton File) file defines skeleton hierarchy, properties of joints and bones and offers shape data optionally. The ASF file is divided into eight sections: *version, name, units, documentation, root, bonedata, hierarchy, skin*. Comments can be added by preceding a hash "#" symbol. The Skeleton is bone based, parent-child relations are described in the *hierarchy* section. The entire hierarchy is relative to the *root*, but in addition every single bone has its own ID, name, direction in global space, lengths, local axis and rotation order. DoF and limits are optional. The predefined file structure doesn´t allow offsets between parent and child bones in skeleton hierarchy, but offers the possibility to insert dummy bones to fill the gaps, or adding division numbers to multiple bones belonging to the same big segment (ACCLAIM 1994). For this reason the ASF file is likely to have more segments compared to other file formats. One ASF file can be associated with multiple AMC files. The AMC file has a rudimental structure, obtaining only two header lines defining the file format type and the units of rotation. The movement data starts frame wise relative to the definitions in the ASF file. The main drawback is, that neither the sampling rate nor the total number of frames is listed in the AMC file, even the name of the associated ASF file is missing (Müller 2007). These aspects might lead to confusions in bigger projects and possibly aggravate the detection of incomplete movement datasets.

BVH

The BVH file format was a proprietary development by Biovision, a motion capture company. BVH stands for Biovision Hierarchical Data. The file is divided into two major sections. The first section [Hierarchy] contains *joint based* hierarchy and angle constraints for the skeleton, the second section [Motion] keeps the number of frames, frame rate and motion data. The skeleton hierarchy is based on one "ROOT" segment with 3 positional and 3 rotational channels. All other segments typically only have 3 rotational channels. Segments are described dependently in a recursive parent-child structure by giving offsets and rotational data for the "JOINT" nodes until an "End Site" node appears. The "End Site" node only contains offset information and is used to infer length and orientation of the last segment. No scaling factor is used, so all of the segments are assumed to be rigid (Menache 2011). In standard BVH Files the world space is defined as a right handed coordinate system with Y-axis as the world up vector. Euler angles order is specified for each bone separately, it is possible to have different orders for different bones (Meredith and Maddock 2001). The [Motion] part of the file is constructed depending to the hierarchical order described in [Hierarchy]. Each column contains the segment channels, starting with the root segment. The first row contains the initial calibration pose, each further row stands for one frame of the movement. The file structure is very user friendly and the file is easy accessible for statistical analysis or spread sheet calculation. The BVH file structure has some minor drawbacks e. g. no information about the environment, used units (e. g. the offsets are measured in) and offers no space for comments.

C3D

The C3D file format was developed in 1987 by Motion Lab Systems as a standardized file format for exchanging biomechanical data between different applications. The C3D file format is one of the most used file formats in gait analysis, biomechanics and motion capture. The file contains raw or processed positional data, analog sample data and information that describes the stored data, such as physical design of the lab, EMG (electromyography) channels, sample rates, patient information, gait timing, force plates etc. The file is expandable, data can be added subsequently without affecting the previous information (Motion Lab Systems 2008). The file is a binary file format, but due to its public specification and free available C3D reader software, a good overview about the recorded data is possible. The C3D format is not skeleton based but instead specifies the 3D trajectories of all markers (Müller 2007). The C3D format is perfectly suitable for biomechanical research. In order to represent skeleton movement only, other skeleton based file formats might have advantages.

HTR

The HTR (Hierarchical Translation-Rotation) format was developed by Motionanalysis. The HTR file format offers a hierarchical skeleton structure, with rotational, translational and scaling information for each segment. Human readable comments can be added after a hash "#" symbol. The file consists of 4 sections, *Header, SegmentNames&Hierarchy, BasePosition* and *FrameData*. The section [header] contains valuable information about frame rate, total number of frames, definition of global axis of gravity, number of segments, Euler rotation order, units, bone lengths axis and scale factor. The file only offers one global Euler rotation order, which is then propagated to all joints (Menache 2011). The bone lengths axis definition forces the joint coordinate systems (JCS) to always have the defined axis aligned to the direction of the next segment bone (Meredith and Maddock 2001). The section [SegmentNames&Hierarchy] defines the skeleton segment names and shows the parent-child relations. At least one segment has to be listed as global and serves as root node within the hierarchy. As a useful feature the file offers a [BasePosition] section, where the position and bone lengths of each segment of the skeleton are fully defined (Tx, Ty, Tz, Rx, Ry, Rz, BoneLengths). The last section [FrameData] provides the movement data, stored in subsections per segment. Each line within a subsection represents a frame number. The HTR file format offers a well-documented header with all necessary information needed to reconstruct the skeleton and motion. The fully defined base position is a convenient feature. A drawback might be that there is only one Euler rotation order applied for all segments, the hardcoded JCS and bone lengths axis might be restrictive for developers.

4.3. Comprehensive file formats

COLLADA

The COLLADA (COLLAborative Design Activity) file format was developed by Sony Computer Entertainment, Khronos Group and a consortium of 3D-software developers in 2004. COLLADA is an xml-based, open-standard format for exchanging digital assets between applications. It has been adopted to ISO as a public specification, ISO/PAS 17506 in 2012. Besides the static 3D, materials and texture information Data, COLLADA offers the possibility to add physics, skeleton, animation and kinematics to the file. Materials can refer to each other e. g. for calculating friction. Bones can be defined as hierarchical dependent static or animated objects with rotational, translational and scaling information.

FBX

FBX, an abbreviation of "Filmbox", is a proprietary 3D file format that was developed by Kaydara in 1996 and acquired by Autodesk Inc. in 2006. It is one of the main 3D exchange formats as used by many 3D tools (BLENDER 2013). Although Autodesk offers a public SDK, FBX is still proprietary without any official documentation besides the SDK documentation. For a detailed description of the SDK see (AUTODESK 2013). The file contains entire scenes, including geometry, lights, cameras, non-uniform rational B-splines (NURBS), skeleton, animation, and skinning. FBX SDK supports reading and writing binary and ASCII format. Due to the lack of documentation regarding the file format itself, developers are dependent on using the SDK. These restrictions exclude this format from being suitable as a standardized DHM file format solution.

4.4. Anthropometric Data

If additional information about the simulated subject is required, it seems beneficial to have a reference file for anthropometric data in addition to the before mentioned data. Several well documented standards and guidelines for anthropometric data (ISO 7250, ISO 15535), humanoid figures (ISO 15536, ISO/IEC 19774 (H-Anim)) and ISB recommendations for biomechanical research (Wu et al. 2002, Wu et al. 2005) exist. In case of a simulation of an existing human (e. g. a worker in a factory) a close proximity to existing proven anthropometric human standards seems necessary to obtain reliable and reproducible data. Therefore a DHM system should be able to import and export anthropometric datasets according to ISO 15535, and consider of ISO 20685 to ensure the compatibility between human measured anthropometrical data and reconstruction of anthropometrical data from 3D scanning. Even for revised structures, a dataset based on ISO 15535 should provide all necessary information for recalculating, transferring and retargeting the data for individual, case specific needs.

5. Discussion and conclusion

Many unsolved problems remain regarding data exchange between different DHM systems. The lack of a standardized solution and the co-existence of a vast number of different file formats interfere with a reliable data exchange. As a consequence, it is currently not possible to establish one standardized comprehensive data exchange format, which would affect the vendor’s business models. Several open source tools have been developed in the past, e. g. the Biomechanical Toolkit (Barre and Armand 2014), which implements Python, Matlab or C++ programming languages to convert different skeleton morphologies. Nevertheless even these tools continue to struggle with too many existing input file formats. Regardless, these tools when combined with a standardized exchange file format, could become a starting point for further developments. For exchanging motion data, the use of complex and large formats is not reasonable. Instead, a triplet of small, widely accepted formats, each for a specific use, seems to satisfy all preconditions for a reliable and potentially lossless data exchange. This could promote the data exchange on a developer’s side, by facilitating the programming of standardized pre- and post-processor interfaces based on accepted exchange format(s). The decision for the recommended formats is based on file size, documentation quality, standardization level and popularity: for the exchange of static 3D data, JT seems to be the most suitable format; for the exchange of motion data the BVH format is recommended and for the accurate anthropometric representation a file format according to ISO15535 seems to produce the most comprehensive and secured solution. Figure 4 shows the recommended data exchange procedure:

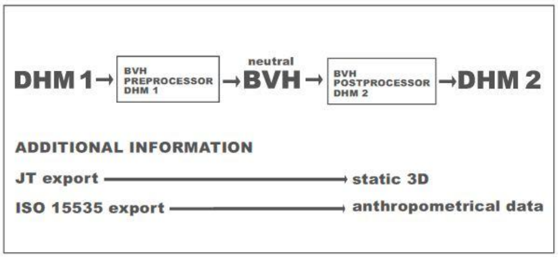


Figure 4: Possible data exchange procedure

Within this proposed framework different BVH preprocessors need to be developed to translate between the different DHM system-BVH structures as long as there is no single accepted BVH structure that is supported (on import and export) by all DHM systems. Researchers developing a new DHM system for their specific research context are encouraged to use the file format and define the skeleton (DOF, naming of joints etc.) as close as possible according to the ISO standard 15536 to ease data exchange and knowledge transfer.

By using the outlined framework posture, anthropometrics and workplace design information could be exchanged between the different DHM systems where needed so that each system can contribute to its best for resolving the given design problem. A matching comprehensive file format for biomechanical information, as for example torques and forces, needs further collaborative research and development. Comprehensive XML based file formats e.g. 3DXML (Dassault Systems 2009), though leading in the right direction, may still have the connotation of a proprietary format. However scientific research projects like UDASim illustrate the recent interest in reliable data exchange between DHM systems, and therefore promote a more confident perspective of the future.

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